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**5 OPTICAL SYSTEM AND A TARGET-SEEKING SYSTEM
COMPRISING AN OPTICAL SYSTEM**

FIELD OF THE INVENTION

10 The present invention relates to an optical system comprising
a first optical unit and a first sensor unit for sensing electromagnetic
radiation. The optical system is arranged such that incident
electromagnetic radiation that originates from some scene outside
of the optical system can reach the first sensor unit by passing via
15 the first optical unit and by following a beam path from the first
optical unit to the first sensor unit.

BACKGROUND OF THE INVENTION AND PRIOR ART

20 ~~The present invention concerns an optical system comprising a first~~
~~optical unit and a first sensor unit for sensing electromagnetic~~
~~radiation. The optical system is arranged such that incident~~
~~electromagnetic radiation that originates from some scene outside~~
~~of the optical system can reach the first sensor unit by passing via~~
25 ~~the first optical unit and by following a beam path from the first~~
~~optical unit to the first sensor unit.~~

30 ~~WO 97/05742-A1 describes such a system. The system a~~
~~system that~~ can be used for detecting infra-red (IR) radiation. The
document describes a switchable mirror which can be set in two
different positions. In a first position, the mirror is not active. In this
position, radiation from an observed scene₁ which goes in through
an objective lens₁ can reach a detector array. In a second position
35 of the mirror, radiation from said ~~the~~ scene is prevented from
reaching the detector array. Instead, radiation from a light emitting
diode is reflected towards the detector array. The light emitting

diode is used as a temperature reference. In this system, it takes a relatively long time to move the mirror from the first to the second position and vice versa.

5 SUMMARY OF THE INVENTION

~~_____The inventor of the present invention has found that it would be~~
~~It is~~ desirable to be able to quickly switch the electromagnetic radiation, which is present, between ~~the first~~an optical unit and ~~the first~~a sensor unit in a system ~~of the kind which has been described in the first paragraph above~~ for sensing electromagnetic radiation, which is arranged such that incident electromagnetic radiation that originates from outside the optical system can reach the first sensor unit via the first optical unit by following a beam path from the first
 10 optical unit to the first sensor unit. Such ~~a~~ quick switching can be advantageous for many different reasons. Among other things, such ~~a~~ quick switching can be used for reducing the probability that the optical system is discovered by devices ~~which~~that search for retroreflexes from such an optical system. Furthermore, ~~such~~
 15 ~~a~~ quick switching can be advantageous in order to prevent ~~that the system is from being~~ destroyed by destroying radiation. ~~Different other~~Additional advantages of the system according to the invention will be clear from the description below.

25 ~~_____The above mentioned purpose and advantages are achieved according to the invention with~~ by the described~~an~~ optical system ~~of the kind which is described in the first paragraph above and which is characterised in that~~ which the optical system also comprises a micromirror matrix unit ~~which~~that comprises a large number of
 30 micromirror elements and which is arranged in ~~said the~~ beam path, wherein the micromirror matrix unit is arranged to be able to be set in at least a first and a second state, wherein in ~~said the~~ first state of the micromirror matrix unit reflects ~~said the~~ incident electromagnetic radiation which reaches the micromirror matrix unit
 35 from the first optical unit such that this electromagnetic radiation reaches the first sensor unit, wherein in ~~said the~~ second state, the micromirror matrix unit reflects ~~said the~~ incident electromagnetic

radiation which reaches the micromirror matrix unit from the first optical unit such that this electromagnetic radiation does not reach the first sensor unit.

5 ____By positioning such a micromirror matrix unit in the beam path, the radiation can be switched very quickly. A micromirror matrix may, for example, be made to switch between two states in less than 10 μ s. The micromirror matrix may thus very quickly be switched between ~~said~~the first and second states. This has many advantages in different contexts. If the optical system, for example, is used as a target-seeking system, the optical system may be exposed to retroreflex searching. Electromagnetic radiation which enters through the first optical unit and which is led to the first sensor unit can be reflected back the same way, since the first sensor unit usually is positioned such that possible reflections from the sensor unit at least partly are reflected back in the opposite direction to the incident radiation. This is used in so-called retroreflex searching. Such a search is done in such a manner that the searching device scans over a certain area in order to look ~~of~~
10 for retroreflexes. In ~~such~~this manner, the optical system can be discovered. Through the present invention, however, the radiation can ~~however~~ be switched very quickly. It is therefore not necessary that radiation from the first optical unit ~~is~~be led to the first sensor unit the whole time. Further advantages of the invention will be described below.

____It can be noted that it is known to in a different manner use a micromirror matrix unit in an IR-detecting system. US Patent No. 5,323,002 ~~thus~~ describes that a light modulator may consist of a digital micromirror device (DMD). This light modulator is used in the beam path from a reference source to a detector. The radiation which has been reflected by the light modulator passes through a ~~none-imaging~~non-imaging optics and further to the detector via a "chopper".

35 ____According to an advantageous embodiment of the present invention, the first sensor unit comprises a large number of sensor

elements and is ~~arranged to be positioned~~ in an image plane in the optical system, which image plane is arranged to be able to constitute an image plane for ~~said the~~ scene. The first sensor unit is ~~thus preferably~~ usually arranged in an image plane for the scene in
 5 question. There are different kinds of sensor systems, ~~inter alia~~ such as so-called staring systems and scanning systems. In a scanning system, the electromagnetic beam is scanned in one or two directions. If the radiation is scanned in two directions, the sensor unit needs only consist of a single sensor element. However, it is
 10 advantageous if the sensor unit comprises a large number of sensor elements. The sensor elements may be arranged in a row. In this case, the beam in question is suitably scanned in one direction (crosswise to the row) such that the row of sensor elements can sense the whole scene from which the electromagnetic radiation
 15 originates. By using a plurality of sensor elements, the scene may thus be sensed faster.

____ According to a further advantageous embodiment, the first sensor unit is such that ~~said the~~ sensor elements are arranged as a
 20 two-dimensional array of sensor elements and ~~wherein the~~ optical system is constructed as a staring system. Since the sensor elements are arranged as a two-dimensional array, no means are needed in order to scan the beam in question. The system is thus, in this case, "staring". This is advantageous, since the scene
 25 thereby can be sensed quickly, since all sensor elements can, at the same time, ~~can sense~~ different parts of the scene. Furthermore, the system can be made smaller and ~~more simple~~ simpler, since no scanning element is needed.

____ The image ~~plan~~ plane, in which the first sensor unit is positioned, is ~~suitable typically~~ arranged in the optical system such that it constitutes an image plane for ~~said the~~ scene when ~~said the~~ scene is ~~positioned located~~ at such a large distance from the optical system that rays from a point in ~~said the~~ scene reach the first
 30 optical unit as at least substantially parallel rays. The optical system is particularly suited to be used when the scene is positioned at a relatively large distance from the optical system.
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The electromagnetic radiation from the scene can thereby be considered to consist of completely or at least substantially parallel rays which enter ~~into~~ the first optical unit.

5 ____ Preferably, the first sensor unit is arranged to sense radiation within the infra-red wavelength range. The system is particularly suited to be used for detecting IR-radiation.

10 ____ The optical system can also comprise a second sensor unit for sensing electromagnetic radiation arranged such that when the micromirror matrix unit is set in a state which is different from ~~said~~ the first state, the micromirror matrix unit reflects ~~said~~ the incident radiation which reaches the micromirror matrix unit from the first optical unit such that this electromagnetic radiation reaches the

15 second sensor unit. ~~Suitably~~ Typically, the micromirror matrix unit can be set in ~~said~~ the second state when it is set such that the incident electromagnetic radiation reaches the second sensor unit. The second sensor unit can thereby be of another kind than the first sensor unit such that the second sensor unit is less disposed to be

20 destroyed by electromagnetic radiation than the first sensor unit. The second sensor unit can, for example, be used if the optical system is exposed to destroying radiation. ~~A switching~~ Switching can then take place such that the second sensor unit is used instead of the first sensor unit. The second sensor unit can thereby

25 be used for, for example, directing a counter attack against the source of the destroying radiation.

30 ____ For example, the second sensor unit can be a quadrant detector. The second sensor unit is ~~suitably~~ preferably not arranged in an image plane for ~~said~~ the scene. A quadrant detector is relatively durable and inexpensive to produce. Such a detector is therefore suitable to be used for the second sensor unit. If it is desired to sense an electromagnetic beam from some destroying source, no image needs to be formed on this sensor unit.

35 Consequently, the second sensor unit is ~~suitable~~ preferably not arranged in an image plane.

____ The optical system can be arranged to prevent the incident electromagnetic radiation from ~~said-the~~ scene from being reflected back to ~~this-the~~ scene from the second sensor unit. This can be done in different ~~manner~~ways. For example, an optical isolator can

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be arranged in the beam path between the first optical unit and the second sensor unit. The second sensor unit can thereby be arranged somewhat inclined, such that it is not arranged perpendicularly relative to the incident radiation. This reduces the risk for retroreflexes.

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____ The optical system may ~~suitably~~ comprise at least one reference source for emitting electromagnetic radiation of a known kind, wherein this reference source is arranged such that electromagnetic radiation from the reference source reaches the

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first sensor unit when the micromirror matrix unit is set in a state which differs from ~~said-the~~ first state. Such a reference source can be used for calibrating the sensor unit. For an IR-system, the reference source thus constitutes a temperature reference. Preferably, the reference source can be set at two different

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____ According to an advantageous embodiment, the reference source is arranged such that electromagnetic radiation from the reference source reaches the first sensor unit when the micromirror matrix unit is set in ~~said-the~~ second state. The calibration of the first sensor unit can thereby take place as soon as the micromirror matrix unit is set in ~~said-the~~ second state.

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____ The optical system ~~suitably comprises~~may comprise a control unit which controls at least the setting of ~~said-the~~ micromirror matrix unit. The control unit can also control the sensing of the first sensor unit, such that the first sensor unit is sensed at a plurality of occasions per second, wherein the control unit is arranged to between these two sensing occasions control the micromirror matrix unit such that it is not in ~~saidthe~~ first state. The first sensor unit thereby only needs to be engaged to sense ~~saidthe~~ scene during the short times when it is actually sensed with regard to incident

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radiation. Between these occasions, the first sensor unit is disengaged from the incident radiation from ~~said~~the scene. This means that the risk that the optical system is discovered by a device which performs retroreflex searching is reduced.

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 According to an advantageous embodiment, the optical system comprises means for detecting if the optical system is exposed to scanning or destroying radiation, wherein the control unit is arranged to control the micromirror matrix unit such that ~~said~~the first state is avoided when ~~said~~the means has detected such ~~a~~-radiation.

~~Suitably, the~~ The micromirror matrix unit is ~~is~~ may thereby be controlled such that it reflects ~~said~~the incident electromagnetic radiation such that it reaches the second sensor unit. ~~Said~~The means for detecting if the optical system is exposed to scanning or destroying radiation can consist of the first sensor unit together with the control unit. The control unit can thus register if suspected scanning radiation is incident ~~onto~~ on the first sensor unit.

20 Alternatively, a separate detector can be used for detecting such radiation. As soon as such radiation is detected, the micromirror matrix unit is ~~suitably~~ preferably switched. Such a switching of the micromirror matrix unit can take place very quickly. Thereby the first sensor unit is protected from being exposed to destroying radiation.

25 The second sensor unit can, as has been explained above, be designed to be less sensitive ~~of~~ to destroying radiation.

 The control unit can also be arranged to individually control the setting of the mirror elements of the micromirror matrix unit in

30 such a manner that the amount of electromagnetic radiation which is reflected by the micromirror matrix unit towards the first sensor unit is controlled by the setting of the mirror elements of the micromirror matrix unit. The micromirror matrix unit can thereby be used for so-called dynamic control. By, for example, "angling away"

35 a number of mirror elements which are randomly selected, the electromagnetic radiation which is reflected towards the first sensor unit is reduced. It ~~can~~ may also be possible to control the setting of

the mirror elements such that, for example, certain peripheral mirror elements are "angled away". If the micromirror matrix unit is suitably properly positioned in the beam path, the micromirror matrix unit can thereby function in a similar manner as a traditional aperture in a camera system.

____ The invention also concerns a target-seeking system. This target-seeking system comprises ~~according to the invention~~ an optical system according to any of the preceding embodiments. The target-seeking system is, for example, a target-seeking missile. The invention is particularly useful in connection with such target-seeking systems.

15 SHORT BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be explained with the help of embodiments, given as examples, and with reference to the annexed drawings.

20 _____ Fig. 1 _____ shows schematically an optical system according to the invention with the micromirror matrix unit set in a first state.

25 _____ Fig. 2 _____ shows schematically the optical system according to fig. 1 but with the micromirror matrix unit set in a second state.

_____ Fig. 3 _____ shows schematically a target-seeking missile.

30 DESCRIPTION OF EMBODIMENTS OF THE INVENTION

_____ Fig. 1 shows schematically an optical system according to an embodiment of the the invention. The optical system comprises a first optical unit 10. Fig. 1 also schematically illustrates a scene in the form of an aeroplane 12 which is located outside of the optical system. The scene 12 is usually located at a large distance from the

optical system such that incident electromagnetic radiation 14 from the scene 12 is incident on the first optical unit 10 as parallel rays.

_____The optical system also comprises a micromirror matrix unit 16 and a first sensor unit 18 for sensing electromagnetic radiation. The micromirror matrix unit 16 has a large number of micromirror elements. Such a micromirror matrix unit (DMD) 16 can for example be of the kind which is provided by Texas Instruments Incorporated in Dallas, Texas. A DMD can for example consist of 1280 x 1024 micromirror elements. Each micromirror element may for example be about the size 16 μm x 16 μm .

_____The micromirror matrix unit 16 is able to be set in at least a first and a second state. In the first state, for example, all micromirror elements can be arranged in one of their end positions. If a sufficient flatness can be achieved, it is also conceivable ~~at possible that~~ all micromirror elements are in their neutral rest position when the micromirror matrix unit 16 is set in the first state. In the second state of the micromirror matrix unit 16, the micromirror elements are ~~suitable~~ arranged such that they are set in their second end positions. In fig. 1, the micromirror matrix unit 16 is considered to be set in the first state. In this state, the micromirror matrix unit 16 reflects the electromagnetic radiation from the first optical unit 10 such that this radiation reaches the first sensor unit 18. The micromirror matrix unit 16 is thus arranged in the beam path 20 from the first optical unit 10 to the first sensor unit 18.

_____The first sensor unit 18 is, according to this embodiment, of the kind where a large number of sensor elements are arranged as a two dimensional array. An example of such a sensor unit is the sensor unit BD MM 003 which is delivered by Sofradir in Chatenay-Malabry, France. Such a sensor unit may for example have 128 x 128 sensor elements. The first sensor unit 18 is thus suitably arranged in an image plane, where an image of the scene 12 is formed. According to the schematic set up which is shown in fig. 1, this means that the first sensor unit 18 is positioned in the focal

plane of the first optical unit 10. It should however be noted that fig. 1 only shows a schematic embodiment. There may in fact be more optical units along the beam path 20. For example, an optical unit may also be arranged in the beam path 20 between the micromirror matrix unit 16 and the first sensor unit 18.

It should also be noted that the embodiment according to fig. 1 is a so-called "staring system". Alternatively, it is also possible to use a scanning system. In such a system, no two-dimensional sensor unit of the kind which is shown in fig. 1 is needed. Instead one or two scanning elements are arranged in the beam path 20.

The first sensor unit 18 is preferably arranged to sense IR radiation. In order to be able to calibrate the first sensor unit 18, the optical system also comprises a reference source 22. The reference source 22 emits electromagnetic radiation 24 of a known kind, i.e. the reference source 22 constitutes a temperature reference. Preferably, also—this temperature can be varied such that the reference source 22 can emit radiation representing at least two different temperatures. When the micromirror matrix unit 16 is set in the first state, radiation 24 from the reference source 22 does not reach the first sensor unit 18. The radiation 24 from the reference source 22 is here represented by broken lines.

According to the preferred embodiment, the optical system comprises also a second sensor unit 26. The second sensor unit is ~~suitably of a more simple and more inexpensive~~ preferably a simpler and less expensive kind than the first sensor unit 18. The second sensor unit 26 may for example consist of a quadrant detector. Such a sensor unit 26 is less sensitive and less disposed to be destroyed by electromagnetic radiation than the first sensor unit 18. In fig. 1 ~~also~~ an optical isolator 30, which will be described more closely in connection with fig. 2, is also schematically shown.

The optical system also comprises a control unit 32. The control unit 32 controls the optical system and co-ordinates the different units with each other. It is thus shown in fig. 1 that the

control unit 32 is connected to the micromirror matrix unit 16, the first sensor unit 18, the second sensor unit 26 and the reference source 22.

5 ~~_____~~As has been ~~mentioned~~described above, there is a risk that the optical system ~~is~~will be exposed to searching radiation. With the help of such searching radiation, an area is searched in order to discover retroreflexes. When such searching radiation enters through the first optical unit 10, this radiation can be reflected by
10 the first sensor unit 18 and exit through the first optical unit 10 to be detected by the searching device. In order to reduce the probability that such a retroreflex via the first sensor unit 18 arises, the control unit 32 is suitably arranged to control the micromirror matrix unit 16 such that the incident radiation from the scene 12 only intermittently
15 reaches the first sensor unit 18. The optical system usually works with a certain image frequency. For example, the image frequency can be 50 Hz, i.e. the first sensor unit 18 is sensed 50 times per second. However, each sensing occasion only needs to last a few ms, for example, less than 5 ms. The control unit 32 can thus
20 control the micromirror matrix unit 16 such that the micromirror matrix 16 assumes ~~said~~the first state only during the time when the first sensor unit 18 is sensed. Therefore, the larger part of the time, no retroreflex via the first sensor unit 18 can occur. This reduces the risk ~~for~~of discovery by ~~the~~such searching radiation.

25 ~~_____~~The optical system can also be arranged with means for detecting such searching radiation. This can be done in that the control unit 32 registers that the first sensor unit 18 is exposed to such radiation. The control unit 32 can thereby be arranged to
30 immediately switch the micromirror matrix unit 16 ~~such~~so that it is no longer in ~~said~~the first state. The micromirror matrix unit 16 can thus be set in at least a second state.

35 ~~_____~~Fig. 2 shows schematically the same system as fig. 1 but with the micromirror matrix unit 16 set in a second state. In this second state, the micromirror matrix unit 16 is set ~~such~~so that incident radiation 14 from the scene 12 does not reach the first sensor unit

18 but instead is directed towards the second sensor unit 26. Since the second sensor unit 26, according to this example, is a quadrant detector, the second sensor unit 26 is ~~suitably~~ preferably not positioned exactly in an image plane.

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_____ If the first sensor unit 18 has been exposed to searching radiation, the micromirror matrix 16 is ~~thus~~ switched such so that the radiation is directed in the manner that is shown in fig. 2. After the discovery with the help of searching radiation, usually a
 10 destroying radiation follows from the device which previously emitted the searching radiation. The purpose of such destroying radiation is to destroy the optical system, in particular the first sensor unit 18. Since the micromirror matrix unit 16 is set in the state which is shown in fig. 2, such a destruction of the first sensor
 15 unit 18 is however avoided. Instead, the destroying radiation is directed towards the second sensor unit 26. This second sensor unit 26 is, as mentioned above, less disposed to be destroyed by such destroying radiation. At the same time, the second sensor unit 26 can be used for controlling a counter attack against the device
 20 which emits the destroying radiation. It is thereby advantageous if the optical system does not reflect the destroying or searching radiation back. This can, according to the invention, be achieved in different ~~manners~~ ways, which can also be combined. The second sensor unit 26 can be arranged ~~such so~~ that it is not arranged
 25 perpendicularly to the incident radiation. This reduces the risk for retroreflex. Furthermore, as has been mentioned, the second sensor unit 26 is preferably not arranged in an image plane. The destroying radiation which hits the second sensor unit 26 is thereby more scattered, which reduces the amount of retroreflected
 30 radiation. Furthermore, an optical isolator 30 can be arranged in the beam path towards the second sensor unit 26. Such an optical isolator 30 can be constructed in different manners which are known to a person skilled in the art. For example, such an optical isolator may consist of a linear polariser in series with a so-called
 35 $\lambda/4$ plate. When the device which emits the destroying radiation has been destroyed, or when destroying or scanning radiation is no longer detected, the control unit 32 can control the micromirror

matrix unit 16 such that it returns to the first state which is shown in fig. 1.

_____The reference source 22 is suitably arranged such that when
 5 the micromirror matrix unit 16 is in the second state as shown in fig. 2, radiation from the reference source 22 is directed towards the first sensor unit 18. The first sensor unit 18 can thus be calibrated when the micromirror matrix 16 is in the second state. When the optical system works normally (i.e. when it is not exposed to
 10 searching or destroying radiation), the system works, as mentioned above, ~~suitably~~ with a certain image frequency. As has been mentioned above, the micromirror matrix unit 16 is ~~suitably~~ preferably switched to the second state between each sensing. Between these sensings, when the micromirror matrix 16 is in the
 15 second state, radiation from the reference source 22 can thus be directed towards the first sensor unit 18. A calibration of the first sensor unit 18 can thus take place between the sensings with the normal image frequency. If ~~possibly~~ a longer time is needed for the calibration, some ~~image-images~~ may be left out in the normal image
 20 frequency. Of course, suitable optics can be arranged in the beam path 24 between the reference source 22 and the first sensor unit 18. Such optics may ~~suitable~~ be arranged in the beam path 24 between the reference source 22 and the micromirror matrix unit 16. Such an optic can consist of an non-imaging optic, for example of
 25 the kind which is shown in the above mentioned US Patent No. 5,323,002.

_____The control unit 32 can also be arranged to individually control the setting of the micromirror elements of the micromirror matrix
 30 unit 16 such that the amount of electromagnetic radiation which is reflected by the micromirror matrix unit 16 towards the first sensor unit 18 can be controlled by the setting of the mirror elements. In this manner, the micromirror matrix unit 16 may be used to control the intensity of the radiation that is incident onto the first sensor unit
 35 18. The intensity can be varied by turning away randomly selected mirror elements of the micromirror matrix unit 16. If the micromirror matrix unit 16 is positioned in a suitable position the beam path 20,

also-selected mirror elements, for example in the periphery of the micromirror matrix 16, may be turned away ~~such~~so that the micromirror matrix unit 16 functions in a similar manner as a normal camera aperture.

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____In the embodiment above, it is ~~specified~~described that the micromirror matrix unit 16 can be set in a first and a second state. With a more advanced micromirror matrix unit 16 it is ~~conceivable~~possible that the micromirror matrix unit 16 can assume more than
10 two states. It is thus ~~conceivable~~possible that in a first state, incident radiation is directed towards the first sensor unit 18, in a second state, incident radiation is directed towards the second sensor unit 26 and in a third state, incident radiation is neither directed towards the first sensor unit 18 nor towards the second
15 sensor unit 26.

____The optical system may suitable ~~be used~~for use in a target-seeking system. Such a target-seeking system can, for example, be arranged on the ground or in an aeroplane. According to a possible
20 embodiment according to the invention, the target-seeking system is a target-seeking missile 34 (see fig. 3) in which an optical system according to the invention is arranged.

____As is clear from the description above, the invention has
25 several advantages. Since the micromirror matrix unit 16 ~~quickly~~ can be quickly switched between at least a first and a second state, the risk that the optical system ~~is~~will be discovered by a system that works with retroreflex searching is reduced. Even if such searching radiation is detected, the risk that the optical system will
30 be ~~is~~-destroyed is reduced since the micromirror matrix unit 16 ~~quickly~~ can be quickly switched to a second state. In this second state, the optical system may also be used to control a counter attack against the device which emits destroying radiation, since the second sensor unit 26 can be engaged for this purpose when
35 the micromirror matrix unit 16 has assumed the second state. Furthermore, according to the invention, so-called dynamic control is achieved since individual mirror elements in the micromirror

matrix unit 16 can be directed such that the amount of radiation which reaches the first sensor unit 18 (and also the second sensor unit 26) can be controlled. Furthermore, the possibility to quickly make calibrations with the help of the reference source 22 is improved. This makes it possible to correct so-called pattern noise in an efficient manner with the help of the invention.

The present invention is not limited to the described embodiments. The invention may thus be modified and varied within the scope of the following claims.